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BENEFICIATION OF VERMICULITE SAMPLES FROM STANLEYVILLE, ONTARIO

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by

J.M. Lamothe* and S.S.B. Wang**

SUMMARY

Grab and core samples from a vermiculite-rich deposit near Stanleyville, Ontario, were submitted to CANMET for beneficiation by the Tweed office of the Ontario Ministry of Natural Resources. Preliminary tests by magnetic, electromagnetic and gravimetric separators were unsuccessful in concentrating the vermiculite. Froth flotation showed potential; however, the attrition action of the impeller resulted in some delamination of the vermiculite. Hydrogen peroxide (H_2O_2) was investigated as an additive to the flotation cell. Used alone it caused some exfoliation and delamination of the vermiculite; however, combined with an amine, it aided the recovery of vermiculite and produced very little exfoliation.

Crushing, sizing, thermal exfoliation and air table recovery of the exfoliated vermiculite were studied in detail. The air table concentrate represented 31% by weight and 61% by volume of the feed and was estimated (by binocular microscope) to contain 80 (82) % of the total (volume) of exfoliated vermiculite. Core samples from drill holes 1 to 5 (12.3 to 27.7 m) and 6 to 10 (27.7 to 43.1 m) were similarly processed. The table concentrate for the upper holes represented 22% by weight and 52% volume of feed and contained 73% of the total volume of exfoliated vermiculite; that from the bottom holes represented 21% by weight and 47% by volume and contained 80 (81.5) % of the exfoliated vermiculite.

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VALORISATION DES ÉCHANTILLONS DE VERMICULITE
PROVENANT DE STANLEYVILLE (ONTARIO)

par

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RÉSUMÉ

Des échantillons extraits par carottage et dragage d'un gîte à haute teneur en vermiculite situé près de Stanleyville en Ontario ont été présentés au CANMET à des fins de valorisation par le Bureau du Ministère des ressources naturelles de l'Ontario du district de Tweed. Des essais préliminaires au moyen des séparateurs magnétique, électromagnétique et gravimétrique en vue d'effectuer la concentration de la vermiculite ont été infructueux. La flottation par mousse a démontré des possibilités; cependant, l'usure causé par l'agitateur a entraîné, dans une certaine mesure, la délamination de la vermiculite. L'eau oxygénée (H_2O_2) a fait l'objet d'une étude visant à déterminer ses propriétés en tant qu'additif à la cellule de flottation. Lorsque l'on n'utilise que de l'eau oxygénée, l'exfoliation et la délamination de la vermiculite se produisent jusqu'à un certain point; cependant, combinée avec une solution aminée, l'eau oxygénée favorise la récupération du minéral et l'exfoliation de celui-ci est minime.

Les procédés de broyage, de criblage, de défoliation thermique et de récupération de la vermiculite exfoliée par concentration sur table ont été étudiés de façon détaillée. Le concentré de la table représente 31 % en poids et 61 % en volume de la matière première et on a évalué (au moyen d'un microscope binoculaire) qu'il contenait 80 (82) % du volume total de vermiculite exfoliée. Les carottes de sondage extraites des trous 1 à 5 (d'une profondeur de 12,3 à 27,7 m) et les échantillons prélevés des trous 6 à 10 (d'une profondeur de 27,7 à 43,1 m) ont été soumis à un traitement identique. Le concentré résultant de la concentration sur table de minéral provenant des trous de la couche supérieure représentait 22 % en poids et 52% en volume de la matière première et contenait 73 % du volume total de vermiculite exfoliée; le concentré résultant de la concentration sur table du minéral extrait du fond du trou représentait 21 % en poids et 47 % du volume de la matière première et contenait 80 (81,5 %) de vermiculite exfoliée.

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INTRODUCTION

In May, 1985, CANMET was approached by the Ontario Ministry of Natural Resources to undertake a beneficiation study on vermiculite from a deposit near Stanleyville, Lanark County, Ontario. In the sixties, an unsuccessful attempt was made by Olympus Mines Limited to exploit this deposit.

Two separate samples were provided for the study. One consisted of a grab sample taken from different locations in the abandoned quarry; the second of drill core from a 43.1 m hole drilled into the deposit.

PREVIOUS WORK

Preliminary investigations by C.G. Bruce (1) in 1950-51 indicated some possibilities for separating vermiculite from the gangue material without exfoliation. The success seemed to rely on delaminating vermiculite while pulverizing the gangue material. Further investigations by H.S. Wilson (2) showed no separation by, for example, magnetic separation and electrostatic effect, and poor separation using heavy liquids to separate by means of density. An investigation on crushing and sizing grab samples from the deposit by R.A. Wyman (3) successfully liberated vermiculite with minimal production of fines (-150 microns), but the author failed to mention whether or not there was an accompanying delamination.

Additional beneficiation studies on Stanleyville vermiculite by R.A. Wyman (4) showed that it was impossible to concentrate vermiculite without exfoliation. On a series of tests on wet beneficiation, wet tabling alone could only separate the "skin" portion which was of no value. Self-grinding tests using chunks of ore as grinding media were executed hoping to liberate and delaminate vermiculite but with little success. Self-grinding combined with processing by Wifley table, Humphrey spiral or wet jig was also unsuccessful. Finally dry beneficiation by air tabling alone or combined with roll crushing and sizing appeared to achieve some concentration of the vermiculite but with considerable loss.

SAMPLE DESCRIPTION AND PREPARATION

Two samples were received, a bulk 160 kg grab sample obtained from several locations in the open pit and a 35 kg drill core sample from a 43.1 m hole drilled into the deposit.

GRAB SAMPLE

The grab sample, contained in 5 bags, was air dried, blended, and a head sample obtained for size, chemical and mineralogical analyses. The material was easily broken by hand. Liberated vermiculite was found in the size range of 2.0 mm and down, but was delaminated under 0.2 mm size. The minus 0.15 mm fraction was discarded because it was completely delaminated and had little commercial value. A summary of initial results follows in Table 1.

Table 1. Size analysis of grab sample

Size fractions mm	% wt	% Vermiculite(1)	Observations
+13	4.6	15±	- vermiculite not liberated
-13, + 5	21.0	15±	- vermiculite not liberated - grey-brown colour
- 5, + 2	23.7	15-25	- vermiculite not liberated - grey-brown colour
- 2, +0.6	27.3	20-30	- most of vermiculite liberated (85%) - brown colour - vermiculite in form of thick book
-0.6, +0.3	13.0	20-25	- vermiculite fully liberated - vermiculite still in book form but thinner - brown colour
-0.3, +0.2	3.5	25	- thin books - dark brown colour
-0.2, +0.15	2.3	20	- delaminated vermiculite
-0.15	4.6	?	- delaminated vermiculite - reddish colour - presence of Hematite-goethite

(1) Evaluated under binocular microscope

The plus 2.0 mm material was crushed by dual roll crusher to liberate the vermiculite without overgrinding. The material produced from the crusher was kept separate from the previously screened minus 2.0 mm material to compare rheological differences in shape or compositions. Table 2 shows the size analysis of the minus 2.0 mm from the original material, the plus 2.0 mm roll-crushed material and the overall % weight distribution of grab sample following crushing of oversize.

Table 2. Size analysis of grab sample products

Size fractions mm	Minus 2.0 mm from original material (% total wt)	Plus 2.0 mm roll-crushed material (% total wt)	Combined weight distributing (% total wt)
+2.0	0.0	4.4	4.4
-2.0 +0.6	27.3	33.2	60.5
-0.6 +0.3	13.0	7.2	20.2
-0.3 +0.15	5.8	2.2	8.0
-0.15	4.6	2.3	6.9
Total	50.7	49.3	100.0

CORE SAMPLE

The core sample consisted of split halves of drill core from 12.3 to 43.1 m divided into 10 sample sections, ST-01 to ST-10. These are described in Table 3.

Following visual examination, the core was divided into two samples for processing, Core sample No. 1 (ST-01 to ST-05, 12.3 to 27.7 m) and Core sample No. 2 (ST-06 to ST-10, 27.7 to 43.1 m). The two were crushed separately using a dual roll crusher in four consecutive stages with intermediate sizing at 2.0 mm. Core sample No. 2 was somewhat harder to crush; to use the jaw crusher for the first stage of crushing would have been more appropriate.

Table 3. Drill core sample description

Interval (m)	Code	Description
0 -12.3	-	- no core available; probably weathered material
12.3-15.4	(ST-01)	- thinly banded, finely divided vermiculite in talcose-like mineral (soft) schistose structure
15.4-18.5	(ST-02)	- similar to ST-01 (soft)
18.5-21.5	(ST-03)	- generally similar to ST-01 and 02 but with harder green coloured material (apatite ?)
21.5-24.6 (1.5 m missing)	(ST-04)	- different to above; 1/3 more massive vermiculite 2/3 essentially barren, light grey-green, harder rock
24.6-27.7	(ST-05)	- mostly finely disseminated (non-banded) vermiculite in light to dark green rock, (soft)
27.7-30.8	(ST-06)	- essentially similar to ST-05
30.8-33.8	(ST-07)	- essentially finely disseminated vermiculite as per ST-05 but with perhaps 10% low grade material
33.8-36.9	(ST-08)	- essentially similar to ST-07 but with minor sections (stringers) of tougher, grey-green rock
36.9-40.0	(ST-09)	- essentially similar to ST-08 with minor barren sections of grey-green rock
40.0-43.1	(ST-10)	- essentially similar to ST-04; up to 1/3 harder, barren rock

BENEFICIATION STUDIES

NON-EXPOLIATED MATERIALDry Beneficiation

i) Magnetic separation

Grab sample: Three different size fractions, $-2.0 +0.6$ mm, $-0.6 +0.3$ mm and $-0.3 +0.15$ mm, were processed in a Carpc magnetic separator at different field intensities. On each sample, the flow pattern of material falling through the magnetic field to the product trays was influenced by the field intensity, indicating some magnetic susceptibilities of the minerals. However, visual examination of the products under a microscope revealed no clear concentration of any minerals.

Drill core sample: Minus $2.0 +0.6$ mm, $-0.6 +0.3$ mm and $-0.20 +0.15$ mm samples of drill core sample No. 1 were also checked on a Carpc magnetic separator. Again, in each case the flow pattern of material falling through the magnetic field varied with its intensity, but no concentration was evident either at low or at high coil current.

ii) Electrostatic separation

Grab sample: Samples used in the magnetic separation tests were also processed by a Coronation electrostatic separator after being dried. At low voltage (5000 volts) "skin" vermiculite was concentrated with ease, but the valuable "thick" vermiculite still remained in the reject portion. At higher voltage ($>10,000$ volts) recovery was increased but vermiculite was not concentrated. It would appear that the "shape factor" plays a major role in concentrating minerals in this type of ore.

Drill core samples: Electrostatic tests were performed on both samples with similar results.

iii) Air tabling

Grab sample: Gravimetric separation was checked using different sized fractions of the grab sample. In each test, separation of vermiculite was not achieved. The small difference in specific gravity between minerals

involved is one reason for the poor performance (Table 4). Also important is the fact that Stanleyville vermiculite is present in form of "books" with an aspect ratio similar to that of associated tremolite and other gangue minerals. Thus separation does not appear to be possible without shape modification prior to beneficiation.

Table 4. Grab sample minerals with specific gravities

Minerals	Specific gravity g/mL
vermiculite	2.6
tremolite	3.0-3.2
talc	2.7-2.8
antigonite	2.5-2.6
calcite	2.7
phlogopite	2.9

Table 5. Denver air table tests: -0.6, +0.3 mm fraction of grab sample*

Product No.	% Wt	Description
1	2.1	coarse grains with low concentration of vermiculite
2	6.2	coarse grains with no definite concentration
3	6.4	medium grains with no definite concentration
4	9.0	medium grains with no definite concentration
5	19.2	medium grains with no definite concentration
6	25.4	fine grains with no definite concentration
7	17.0	fine grains with no definite concentration
8	14.7	small concentration of "skin" vermiculite
Total	100.0	

*No exfoliation prior to test

Drill core samples: Two sized samples of drill core were also checked on the air table. Results were not too impressive (Tables 6 and 7).

Table 6. Denver air table: -2.0, +0.6 mm fraction from drill core, sample 1*

Product No.	% Wt	Description
1	0.4	coarse grains with low vermiculite content
2	8.0	coarse grains with low concentration of vermiculite
3	12.8	medium grains with no definite concentration
4	22.0	medium grains with no definite concentration
5	27.7	medium grains with no definite concentration
6	20.2	fine grains with no definite concentration
7	8.0	fine grains with some concentration of vermiculite
8	0.9	fine grains with high concentration of "skin" vermiculite
Total	100.0	

*no exfoliation prior to test

Table 7. Denver air table: -0.6, +0.3 mm fraction from drill core, sample 2*

Product No.	% Wt	Description
1	2.4	coarse grains with low concentration of vermiculite
2	5.1	coarse grains with no definite concentration
3	3.4	medium grains with no definite concentration
4	7.8	medium grains with no definite concentration
5	17.4	medium grains with no definite concentration
6	26.0	fine grains with no definite concentration
7	27.4	fine grains with no definite concentration
8	10.5	fine grains with small concentration of "skin" vermiculite
Total	100.0	

*no exfoliation prior to test

iv) Delamination tests

To enhance the shape factor difference between the vermiculite and gangue minerals, delamination tests using a disc pulverizer were carried out, hoping to achieve a partial delamination with minimum loss of vermiculite in the fines (-0.15 mm). Table 8 shows the results of pulverizing the samples at different gaps between disc plates. Vermiculite was concentrated when the discs plates were close, but severe delamination occurred with mostly 'skin' vermiculite resulting. With a broader gap, 'book' vermiculite was preserved and exfoliable, but grade was low. The production of 'skin' vermiculite in the fine fraction renders this process impractical.

Table 8. Disc pulverizer results on grab sample

Size of feed (mm)	Disc gap	Product fineness (mm)	% Wt	% Vermiculite*
-2.0, +0.6	wide	+1.5	94.5	40
		-1.5	5.5	presence of 'skin'
-2.0, +0.6	narrow	+1.5	83.0	50 with more 'skin'
		-1.5	17.0	presence of 'skin'
-2.0, +0.6	narrow	+1.5	61.8	60 mostly 'skin'
		-1.5	38.2	presence of 'skin'
-0.6, +0.3	just touching	+1.5	62.8	50 mostly 'skin'
		-1.5	37.2	presence of 'skin'
-2.0, +0.6	just touching	+1.5	64.8	40 mostly 'skin'
		-1.5	35.2	presence of 'skin'

*determined visually under microscope

Wet Beneficiation

i) Flotation

The minus -0.3 , $+0.15$ mm fractions from grab and core samples were floated using a Denver laboratory flotation cell to examine the possibility to upgrade the vermiculite content without further optimization. The test results are shown in Table 9. This study demonstrated some flotation differences between weathered material (grab sample) and core sample. The

vermiculite in the grab sample floats best in an alkaline pulp when tertiary amine is used as a vermiculite collector. However, with the same collector, vermiculite in the drill core samples did not float in a high pH pulp but floated readily in acidic condition.

Table 9. Flotation test results

Sample description	pH ¹	Reagent	Description
-0.3, +0.15 mm (grab sample)	10	amine ²	vermiculite floats with some talc and tremolite 60% vermiculite in float product
-0.3, +0.15 mm (grab sample)	4		poor flotation of vermiculite
-0.3, +0.15 mm (grab sample)	4	oleic acid & frother ³	flotation of talc with some vermiculite
-0.3, +0.15 mm (core sample)	10	amine ²	no flotation
	4	amine ²	vermiculite floats with impurities 70% vermiculite in float product

1 - pH regulated with H₂SO₄ and Na(OH)

2 - tertiary amine, Ethomeen T/15

3 - Dow D250

In each test, attrition of the samples by the cell propeller was excessive, even at low speed. Coarse vermiculite was delaminated and excessive amounts of slime produced. Also, conventional flotation cells have limits in the flotation of coarse grain material, and vermiculite in the -2.0, +0.6 mm of size would be difficult to float. This could be compensated for by using a column flotation cell instead of a mechanical type. The quiescent flow in the column and the self regulating bubbles in the froth zone should provide better results when floating coarse grain material. With the absence of agitators, delamination of vermiculite and the sliming of the gangue minerals, which increases reagent consumption, should be minimized. However, this should be confirmed by further testing.

ii) Hydrogen peroxide

A few tests were made to examine the effect of hydrogen peroxide on vermiculite. A sample of the -0.6, +0.15 mm fraction from the grab sample was treated in a water solution containing 15% by volume of hydrogen peroxide. After a few minutes, bubbles appeared on the surface of the vermiculite grains. This was followed by the partial exfoliation of some vermiculite particles. After 20 min. a portion of the vermiculite was completely exfoliated and delaminated; the remainder was only partially exfoliated or unchanged. Repetitions of the test at different concentrations of H_2O_2 gave similar results but with different reaction periods. Some grains of vermiculite reacted quickly to H_2O_2 and exfoliated, but too long a reaction time delaminated the same grain. Other particles of vermiculite were slow to exfoliate. This "uncontrollable" phenomenon seemed to have no relation to the size of the grains, but rather was controlled by the pH. At low pH, (2-4), bubble formation was low and at high pH (10) the reaction lasted longer. This is probably due to degradation of H_2O_2 by the high concentration of H^+ .

Water solution with 10% volume of H_2O_2 and tertiary amine as collector were combined with some feed to initiate flotation with the help of bubble formation. Because the bubbles form only on vermiculite mineral, this phenomenon creates high selectivity during a quiet flotation. Results are promising. When enough bubbles form on the surface of vermiculite grains, the vermiculite selectively rises to the surface of the cell and can be removed. In one test floated material was skimmed off after 20 min. The float consisted essentially of exfoliated vermiculite (95-98%) with little 'skin'. In another, floated material was skimmed off every 2 min. In this case, the float consisted of 60% or more of unexfoliated vermiculite.

EXFOLIATED MATERIAL

Gravimetric separation was possible when thermal exfoliation of vermiculite was previously processed. Expanded vermiculite was separated from the gangue mineral by air tabling due to their shape, size and bulk specific gravity differences. However, material had to be sized before exfoliation to prevent small gangue particles from reporting with large exfoliated vermiculite grains and also to minimize delamination when sizing and handling expanded vermiculite.

Grab Sample

A representative sample was first screened at 2.0 mm to separate unliberated vermiculite grains (Fig. 1). All products from the two fractions were then kept separated to check for differences in performance or behaviour during subsequent processing. The liberated portion (-2.0 mm) was then screened to produce -2.0 +0.6, -0.6 +0.3 mm, -0.3 +0.15 mm and -0.15 mm fractions, the latter being discarded. The +2.0 mm portion which contained some lump material was crushed and sized twice to liberate all grains. A dual roll crusher equipped with "soft" shock absorbers was chosen for its satisfactory performance on selective crushing of vermiculite and gangue minerals. When being crushed, the former was delaminated to a certain degree only but the latter was pulverized due to its brittle characteristic. The gap between rolls was controlled to minimize production of fines and was decreased at the second stage of crushing. The product was screened to produce +2.0 mm, -2.0, +0.6 mm, -0.6 +0.3 mm and -0.3 mm fractions, the latter being rejected because of the low vermiculite content.

All fractions were next separately thermally-treated in a laboratory tube furnace at 2000°F to expand the vermiculite. Residence time increased with the fineness of feed particles. Heat treatment was not optimized despite the knowledge that residence time, temperature, and residual moisture is directly related to the exfoliation and the fragility of vermiculite after treatment. Rather the emphasis was on upgrading and recovery of vermiculite by mechanical means.

Each exfoliated fraction was tested on a 300 x 500 mm deck Denver air table at different settings depending on the size of the feed material. Products were weighted and the corresponding bulk volume measured using a graduated cylinder. The grade of each product was evaluated visually. After comparisons, products were combined to form three products from air table test. A product was considered a concentrate when it contained more than 90-95% vermiculite by volume and a reject when vermiculite content was lower than 30-40% by volume. Any product grading between those limits was considered as middlings. Practically, the middling was the result of mineral segregation in the air table feeder, causing mineral band fluctuations on the table. In actual production, the middlings would be returned to the feed point for recycling.

Results of these tests are shown in Table 10. Grade calculations were based on a visual examination which was made with care. The overall concentrate product recovered was only 31.1% by weight but in terms of percent of total volume (exfoliated) this was more than 61%. Vermiculite recovery was 82% by volume (exfoliated). The middlings portion contained 11.3% of total weight and 9.8% of total volume (exfoliated). This represented 11.4% of the vermiculite found in the feed (recovery). Finally, rejects contained as much as 57.6% total weight but only 28.6% in terms of total volume. Practically all the vermiculite (82% by volume) reported in the concentrate. Volume recovery of vermiculite would increase to 93.4% if middlings were recirculated.

Core Samples

Samples No. 1 and 2 were treated separately and as per the flow chart, Fig. 2. Samples were crushed in a dual roll crusher followed by sizing in a Kotex screen for four consecutive stages. The gap between rolls was decreased after each pass to reduce size of material and to liberate vermiculite with minimum delamination and fines production. Undersized portions of each stage were combined and screened to obtain +2.0 mm, -2.0 +0.6 mm, -0.6 +0.3 mm and -0.3 mm fractions. Each fraction was treated separately in tube furnace for exfoliation followed by a cooling period. Portions were then tested on a Denver air table to separate the minerals.

1) Sample No. 1

The drill core in this sample was easily crushed but some chunks had a tendency to "agglomerate". Most of the interlocked grains "agglomerates" were broken after sizing but some remained in the +2.0 mm fraction.

Results of exfoliation and air tabling appear in Table 11. The vermiculite content was evaluated by two different methods: visual examination under microscope and XRD measurements using vermiculite samples from Libby, Montana, and Parkdale, Colorado, as standards. The XRD method gave higher vermiculite content for each product. This method was based on a % of mass, whereas the first method was based on % volume because of the visual aspect. The % vermiculite by visual examination was used to calculate percentage recovery by volume of exfoliated product.

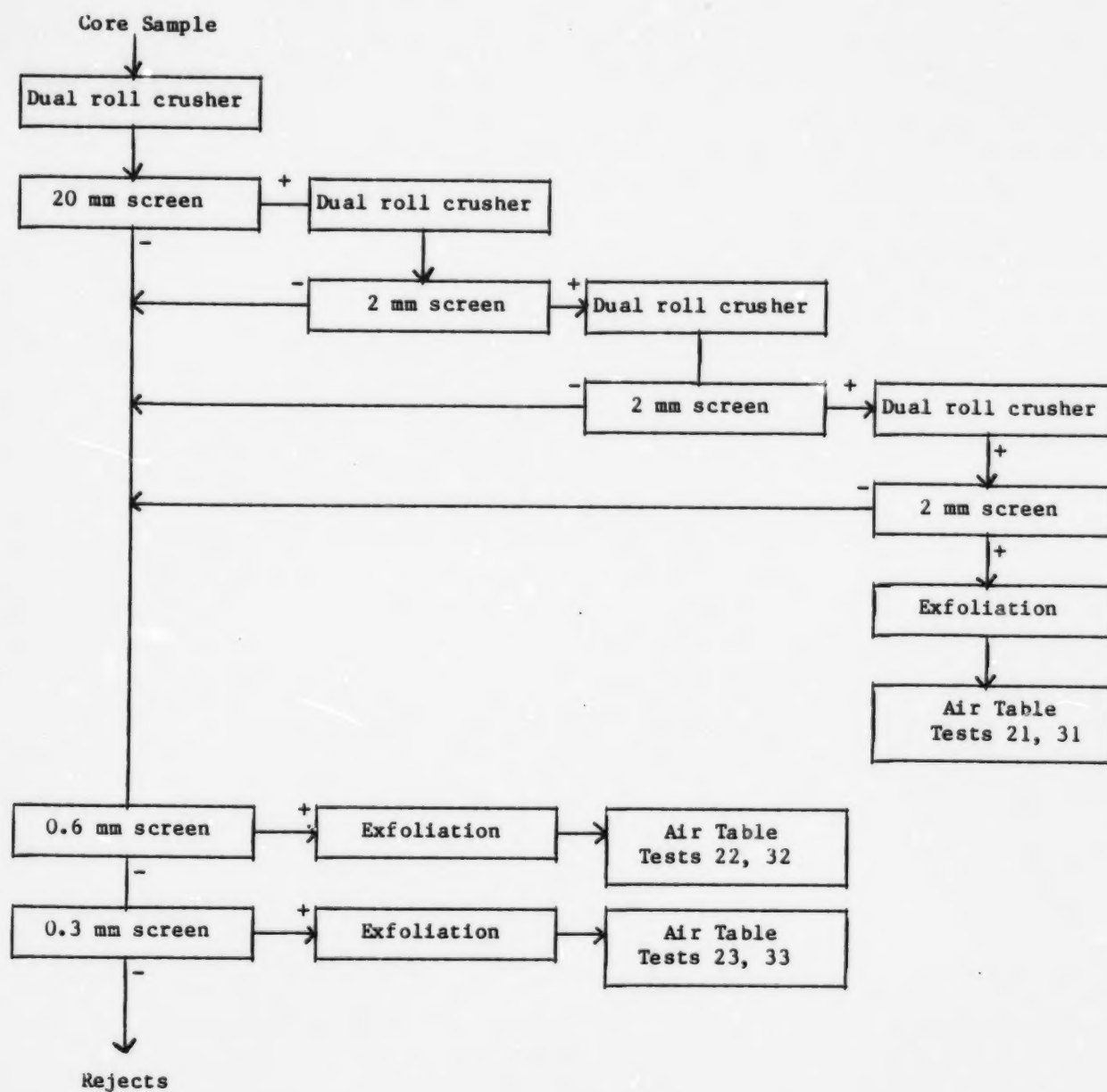


Fig. 2 - Drill core flow diagram

Table 11. Air table tests, exfoliated drill core sample No. 1

Denver Air Tables																		
Test No.	Sample Description and Size Fraction (mm)	% Total Wt	Product No.	% Vermiculite		% Weight		% Volume (Total)	Bulk Density (g/cc) (3)	% Distribution of Vermiculite Mineral (4)		Products				% Amphibole (2)		
				(1)	(2)	Per Test	Total			Per Test	Total	% Wt Total	% Vol Total	% Wt Total	% Vol Total			
Drill core sample no. 1 (After 4 stages of roll crushing)																		
21	+2.0	8.4	1 2 3 4 5 6 7 8 Sub-total	5 10 30 90 98 100 100 100 100	28-34 57-63 60-67 95-96 100 100 100 100 100	4.8 25.0 19.0 16.7 14.3 11.9 7.1 1.2 100.0	0.4 2.1 1.6 1.4 1.2 1.0 0.6 0.1 8.4	0.2 1.0 0.9 1.6 3.1 3.3 1.6 0.2 (11.9)	1.38 1.13 0.95 0.45 0.20 0.16 0.19 0.27 (0.37)	3.5 45.1 51.4 100.0	0.5 6.4 7.3 14.2				4.1 2.6 1.7 5.1	2.1 4.7 5.1 5.1	69-64 41-35 37-31 5-4 - - - -	
22	-2.0, +0.6	69.2	1 2 3 4 5 6 7 8 Sub-total	5 5 20 90 98 100 100 100	17-22 53-59 81-85 100 100 100 100 100	11.4 31.3 19.4 13.2 12.6 7.7 3.6 5.8 100.0	7.9 21.7 13.5 9.2 8.7 5.3 2.5 0.4 69.2	3.2 10.1 7.4 10.9 20.7 14.6 6.2 0.6 (73.7)	1.27 1.12 0.95 0.44 0.22 0.19 0.21 0.37 (0.49)	4.1 18.3 77.6 100.0	3.1 14.0 59.3 76.4				43.1 9.2 16.9 42.1	20.7 10.9 4.1 4.5	14-10 25-22 17-14 - - - -	
23	-0.6, +0.3	12.7	1 2 3 4 5 6 7 8 Sub-total	5 7 30 70 95 100 100 100	48-55 77-81 90-93 100 100 100 100 100	17.3 31.5 15.0 10.2 9.4 7.9 6.3 2.4 100.0	2.2 4.0 1.9 1.3 1.2 1.0 0.8 0.3 12.7	0.9 1.9 1.1 0.9 1.2 1.3 0.6 0.3 (9.3)	1.26 1.09 0.94 0.73 0.52 0.39 0.30 0.27 (0.71)	8.9 11.4 79.7 100.0	0.7 0.9 6.3 7.9				8.1 1.3 3.3 4.5	3.9 0.9 6.3 7.9	30-26 15-12 9-6 - - - -	
24	-0.3, +0.2	2.5		20	11-14													23-22
25	-0.2, +0.15	2.5		20	13-15			5.1	1.00		1.5					5.1		21-20
26	-0.15	4.7		20	15-18													45-44
	Total	100.0					100.0	100.0	(0.52)		100.0	21.9	51.7	13.1	16.5	65.0	31.8	

1 - Z vermiculite determined visually under microscope;

2 - Z vermiculite determined by 480 using Libby vermiculite as standard (first number) or Libby and Colorado vermiculites as standard (second number);

3 - weighted samples were poured into graduated cylinder and shaken 5 times before volume was measured;

4 - Z distribution were calculated from Z vermiculite by microscope and on Z volume

The concentrate products represented 21.9% of total weight and 51.7% of total volume (exfoliated). This gave a recovery of 72.9% by volume of all vermiculite contained in the feed. The middlings were also high and presented 13.1% of total weight, 16.5% total volume (exfoliated) which represented 21.3% recovery of vermiculite. Considering the middlings as recirculated and recovered, the reject portion represented only 5.8% of the vermiculite found in the feed (by volume).

ii) Sample No. 2

The crushing and sizing of this drill core produced more fines (-0.3 mm) than for sample No. 1 although the former appeared to be tougher. This could be due to the high content of "brittle" minerals which is pulverized rather than broken. Results of exfoliation and air tabling appear in Table 12 and were similar to those for sample No. 1 (Table 11). Concentrates represented 20.6% of total weight and 46.9% of total volume indicating a possible recovery of 81.5% by volume of the vermiculite contained in the head. Considering the middlings as recirculated and recovered, performance was better and attained up to 92.5% recovery (by volume) of the vermiculite.

CONCLUSION

Based on tangible results obtained from this study on the given samples, our recommendations for a feasible circuit would be:

1. use of a low temperature drier to eliminate trapped moisture affecting screening efficiencies.
2. stage crushing and sizing to minimize fines production; the use of dual roll crusher is satisfactory if rolls turn at a speed to prevent shearing action (delamination) of vermiculite.
3. separate exfoliation of the different size fraction to maximize gravimetric separation.
4. use of air tables to separate expanded vermiculite from the gangue minerals with recirculation of middlings to the table's feed point.

Table 12. Air table tests, exfoliated drill core sample No. 2

			Denver Air Tables										Products						Z Amphibole (2)
Test No.	Sample Description and Size Fraction (mm)	Z Total Wt	Product No.	Z Vermiculite		Z Weight		Z Volume (Total)	Bulk Density (g/cc) (3)	Z Distribution of Vermiculite Mineral (%)		Concentrate		Middlings		Tailings			
				(1)	(2)	Per Test	Total			Per Test	Total	Z Wt Total	Z Vol Total	Z Wt Total	Z Vol Total	Z Wt Total	Z Vol Total		
Drill core sample no. 2 (After 4 stages of roll crushing)																			
J1	+2.0	3.1	1	5	13-16	6.5	0.2	0.1	1.26	13.8	0.4								78-12
			2	5	30-36	25.7	0.8	0.5	1.15										66-80
			3	15	33-42	22.5	0.7	0.4	1.08										50-50
			4	30	29-36	19.4	0.6	0.4	0.97										67-61
			5	70	100	12.9	0.4	0.6	0.50	24.1	0.7			0.4	0.6				-
			6	95	100	6.5	0.2	0.5	0.26	48.3	1.4								-
			7	100	100	3.2	0.1	0.3	0.28										-
			8	100	100	3.2	0.1	0.2	0.46	13.8	0.4								-
		Sub-total				100.0	3.1	3.0	(0.73)	100.0	2.9				0.1	0.2			
J2	-2.0, +0.6	64.6	1	5	12-16	9.6	6.2	3.1	1.40										73-12
			2	5	15-28	27.3	17.7	10.1	1.24	3.0	2.3								45-65
			3	7	39-45	21.0	13.6	8.8	1.09										53-50
			4	30	76-81	16.3	10.5	9.7	0.76	6.8	5.2			10.5	9.7				8-6
			5	95	100	14.6	9.4	19.0	0.35										-
			6	100	100	7.3	4.7	13.8	0.24	66.4	68.7		16.6	39.7					-
			7	100	100	3.4	2.2	6.2	0.25										-
			8	100	100	0.5	0.3	0.7	0.31	100.0	76.2								-
		Sub-total				100.0	64.6	71.4	(0.64)										
J3	-0.6, +0.3	18.2	1	5	29-34	15.9	2.9	1.5	1.34										54-50
			2	7	71-76	27.6	5.0	3.1	1.15	6.3	1.1								20-10
			3	20	86-89	13.2	2.4	1.6	1.07										14-11
			4	60	94-95	11.5	2.1	1.5	0.97	29.0	5.1			4.2	3.7				6-3
			5	90	96-97	11.5	2.1	2.2	0.70										4-3
			6	100	100	9.9	1.8	2.5	0.51	64.7	11.4		3.7	6.4					-
			7	100	100	7.7	1.4	2.7	0.37										-
			8	100	100	2.7	0.5	1.2	0.30	100.0	17.6								-
		Sub-total				100.0	18.2	16.3	(0.79)										
J4	-0.3, +0.15	5.9	20	5-7			14.1	9.3	1.00	100.0	3.3				14.1	9.3		56-55	
J5	-0.45	8.2	20	7-8														63-64	
	Total	100.0					100.0	100.0	0.71	100.0	100.0		20.6	45.9	15.1	14.0	64.3	39.1	

1 - Z vermiculite determined visually under microscope;

2 - Z vermiculite determined by XRD using Libby vermiculite as standard (first number) or Libby and Colorado vermiculites as standard (second number);

3 - weighted samples were poured into graduated cylinder and shaken 5 times before volume was measured;

4 - Z distribution were calculated from Z vermiculite by microscope and on 4 volume

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